Respiratory muscle training for tetraplegic patients: A literature review

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This paper reviews the evidence concerning the effectiveness of respiratory muscle training for tetraplegic patients. While respiratory muscle strength/endurance and/or pulmonary function have been shown to improve after inspiratory muscle training, a lack of controlled studies means it is not possible to exclude spontaneous recovery from being responsible for the improvements seen. It is not known if inspiratory muscle training improves quality of life or decreases morbidity. There are limited data which suggest that, for ventilator dependent tetraplegics, strengthening the muscles of the neck and upper thorax may improve vital capacity and allow limited ventilator-free time. The effectiveness of other techniques such as glossopharyngeal breathing, expiratory muscle training and exercise as methods of improving respiratory muscle strength/endurance is unknown. **[Stiller K and Huff N (1999): Respiratory muscle training for tetraplegic patients. A literature review. *Australian Journal of Physiotherapy* 45: 291-299]**

Key words: Breathing Exercises; Physical Therapy; Quadriplegia; Respiratory Muscles

Introduction

Although spinal cord injury (SCI) is relatively rare, with a prevalence of approximately 15 per million persons in Australia, the ongoing costs associated with the long term care of patients with SCI is estimated to be in the order of 200 million dollars per year (O'Connor and Cripps 1997). Of patients with SCI, approximately half will suffer injury to the spinal cord in the cervical region (O'Connor and Cripps 1997). Complete lesions in this area result in paralysis of muscles innervated by both the damaged spinal segment and all segments below this level. Thus tetraplegia results.

The respiratory function of tetraplegic patients with lesions below C3 is compromised by the paralysis of the intercostal muscles, with the diaphragm and accessory respiratory muscles (such as the sternocleidomastoids and upper trapezius), which are innervated above the level of the lesion, remaining as the inspiratory muscles (Mansel and Norman 1990). Tetraplegic patients with lesions above C3 will also lose diaphragmatic function and, in most instances, be dependent on mechanical ventilation (Mansel and Norman 1990). As a result of the paralysis of inspiratory muscles, there is a marked reduction in the ability of tetraplegics to achieve full lung inflation, which predisposes them to the development of alveolar hypoventilation (Haas et al 1985). In addition, forced expiratory manoeuvres (eg coughing) are adversely affected, as these techniques normally rely on intercostal and abdominal muscle activity as well as passive recoil of the lung and chest wall (Mansel and Norman 1990). Thus tetraplegics have a reduced ability to cough and clear pulmonary secretions effectively, which may lead to reduced airway clearance. As a result of these abnormalities, hypoventilation, atelectasis, retention of secretions, infection and impaired gas exchange may develop (Ledsome and Sharp 1981, Mansel and Norman 1990, Rose et al 1987).

Pulmonary function tests performed on recent complete tetraplegics have demonstrated significant, dramatic reductions in spirometric parameters, with forced vital capacity (FVC), forced expiratory volume in one second and maximal mid-expiratory flow rate reduced to approximately 30 per cent of predicted normal values (Ledsome and Sharp 1981, Stiller et al 1992). Similarly, maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) and measures of respiratory muscle endurance are decreased to well below normal range (Black and Hyatt 1969, Gounden 1997, Hopman et al 1997, Loveridge and Dubo 1990, Rose et al 1987). Although most patients demonstrate some improvement in lung function over time, spirometric parameters only increase to approximately 40 to 50 per cent of predicted normal values (Haas et al 1985). As a consequence of these respiratory abnormalities, the risk of pulmonary complications is increased significantly for tetraplegic patients and pulmonary complications are one of the most common causes of mortality and morbidity, particularly in the acute stage (Mansel and Norman 1990). The majority of tetraplegic patients also report symptoms of breathlessness either at rest or during activity (Spungen et al 1997) and show electromyographical (EMG) evidence of diaphragmatic fatigue during exercise (Sinderby et al 1996).

In view of their reduced inspiratory and expiratory ability, tetraplegic patients would seem an appropriate group to receive respiratory muscle training (RMT) aimed at increasing the strength and/or endurance of their inspiratory and/or expiratory muscles as part of their rehabilitation. Although there have been recent excellent review articles concerning the effectiveness of RMT (Goldstein 1993, Pardy and Rochester 1992), these have not specifically addressed RMT for tetraplegic patients. A telephone interview with senior physiotherapists working in the six major spinal injuries units in Australia, conducted as a precursor to this review, found that formal RMT was not conducted at any stage of the rehabilitation of tetraplegic patients in any of the units. This conflicts with practice in the United States of America, where RMT is used extensively with this patient group (Derrickson et al 1992). The reason for patients in Australian spinal injuries units not receiving RMT is unclear, but may be due to the maintenance of an historical precedent or a lack of awareness by Australian physiotherapists of RMT as a treatment option. Alternatively, physiotherapists may have chosen not to use RMT on the basis of personal experience or published research. It is also possible that the low incidence of new tetraplegic patients per year and the spread of these patients through geographically isolated units in Australia may contribute to a lack of depth of experience in this particular area. Potentially, this may mean that tetraplegic patients in Australia are not receiving an important component of their management.

This paper reviews the evidence that RMT is effective for tetraplegic patients. If RMT is effective, it should be possible to document improvements in respiratory muscle strength and/or endurance and pulmonary function following a period of training. It could also be hypothesised that if RMT is effective, it may reduce the incidence of pulmonary complications and improve the exercise capacity and quality of life of tetraplegic patients. Thus this review will address the following questions: Does RMT improve respiratory muscle strength, respiratory muscle endurance or pulmonary function? Does RMT reduce the incidence of pulmonary complications and/or improve exercise capacity and quality of life? Based on the findings of this review, recommendations for Australian physiotherapists working with this patient group will be made regarding the use of RMT.

To ensure that all relevant articles were obtained, literature searches were done on CD ROM databases for Medline and CINAHL (Cumulative Index for Nursing and Allied Health Library). In addition, reference lists of articles were examined to identify additional relevant articles. This paper does not attempt to review the effectiveness of other types of respiratory intervention for tetraplegic patients, nor studies that involved animals.

Does RMT improve respiratory muscle strength, respiratory muscle endurance or pulmonary function? Table 1 provides a summary of the 12 studies identified that evaluated the effect of RMT on respiratory muscle strength/endurance or pulmonary function. The types of RMT that have been investigated include inspiratory muscle training (IMT) using flow resistive devices, pressure threshold devices or abdominal weights (Biering-Sorensen et al 1991, Derrickson et al 1992, Gross et al 1980, Hornstein and Ledsome 1986, Huldtgren et al 1980, Loveridge et al 1989, Rutchik et al 1998) and expiratory muscle training (EMT) using flow resistive devices (Gounden 1990). The rationale for the use of flow resistive devices is that the patient has to use additional force to inhale (or exhale) through a narrowed orifice. Pressure threshold devices require the generation of a pre-determined pressure throughout inspiration and abdominal weights provide resistance to the descent of the diaphragm into the abdomen during inspiration, thus necessitating increased diaphragmatic activity. The other types of RMT that have been investigated are strengthening exercises for the accessory muscles of inspiration in the neck and/or upper thorax using EMG biofeedback (Gallego et al 1993, Morrison 1988), a program of incentive spirometry and arm cycle ergometry (Walker et al 1989) and glossopharyngeal breathing (Clough 1983). The latter involves a series of pumping strokes using the lips, tongue, soft palate and pharynx to generate gulps of air which are then pumped into the trachea. Each gulp is reported to add 25-120mL of air and, by a series of gulps (as many as 20) vital capacity is augmented (Alvarez et al 1981).

As can be seen from Table 1, three studies included control groups (Gounden 1990, Huldtgren et al 1980, Loveridge et al 1989), with random allocation to groups performed in two of these (Gounden 1990, Loveridge et al 1989). Patients in the control groups received either no therapy at all (Huldtgren et al 1980, Loveridge et al 1989) or conventional rehabilitation with the specific exclusion of breathing exercises (Gounden 1990) and were aware of the study design in at least two of these studies (Gounden 1990, Loveridge et al 1989). Another study compared two methods of IMT (Derrickson et al 1992) and eight studies evaluated patients before and after a program of RMT (Biering-Sorensen et al 1991, Clough 1983, Gallego et al 1993, Gross et al 1980, Hornstein and Ledsome 1986, Morrison 1988, Rutchik et al 1998, Walker et al 1989). There were methodological limitations with all of the studies. Sample size was low, examiner blindness and the reliability of the outcome measurements was not investigated in any of the studies, and a power calculation was performed in only one study (Derrickson et al 1992). Additional criticisms such as lack of randomisation of patients to groups and inconsistent and poor reporting of outcomes were also apparent in the study by Huldtgren et al (1980).

To summarise the studies outlined in Table 1, there has been only limited research into the effect of RMT on respiratory muscle strength, respiratory muscle endurance or pulmonary function for tetraplegic patients. While RMT has been shown to have beneficial effects on respiratory muscle strength/endurance and/or pulmonary function, the lack of randomised control groups in all but two studies means that it is not possible to exclude spontaneous recovery or a training effect from the measurement procedures as being responsible for the changes observed.

Does RMT reduce the incidence of pulmonary complications and/or improve exercise capacity and quality of life? Gross et al (1980) and Hornstein and Ledsome (1986) (Table 1) reported that patients' symptoms, such as shortness of breath while talking or eating, and fatigue when sitting in their wheelchairs for prolonged periods of time, disappeared as IMT progressed. In an attempt to quantify the effect of RMT on breathlessness, patients in the study by Rutchik et al (1998) (Table 1) used the modified Borg scale to rate their level of resting dyspnoea before and following the eight-week program of IMT. Although a mean decrease of 43 per cent was found following the program, this did not achieve statistical significance.

In the single case study of the ventilator-dependent C1 tetraplegic, Morrison (1988) (Table 1) found that the improvement in the patient's vital capacity after the six sessions of EMG biofeedback allowed the patient to tolerate 35 minutes off the ventilator. After a further five sessions of training, but without the EMG biofeedback, this had regressed to 7.5 minutes, mainly as a result of loss of motivation to attempt longer periods off the ventilator. While this period of time may not seem substantial, it represented a clinically significant improvement as it allowed the patient to be transferred without the need for constant mechanical ventilation, and with one assistant rather than two. Similar improvements were reported by Gilgoff et al (1988) who evaluated the effectiveness of strengthening the accessory muscles of inspiration in the neck, in this case without the use of EMG biofeedback. In this study, eight tetraplegic children (aged 3-16 years old) with no diaphragmatic activity and therefore mechanically ventilated, were given manual resistive exercises of the neck muscles and other activities using "oral motor control". The period of training ranged from a few weeks to more than one year. Eventually, seven of the eight patients were able to stay disconnected from the ventilator for a mean of 3.5 hours (range 20 minutes to 12 hours). This ventilator-free time allowed for easier transfers and the ability of patients to survive accidental or unattended short-term disconnection from the ventilator.

Finally, following the cycle ergometry program for 15 chronic tetraplegic patients outlined earlier (Walker et al 1989) (Table 1), significant increases in the maximum power output suggested an increased level of endurance for arm ergometry activity.

In summary, there has been no systematic evaluation of the effect of RMT on the incidence of pulmonary complications and/or its ability to improve exercise capacity and quality of life. In the studies which have demonstrated increases in pulmonary function and/or

Table 1. Summary of studies investigating the effectiveness of RMT on respiratory muscle strength/endurance or pulmonary

Authors	Number of subjects, level and duration of lesion	Description of treatment group(s)
Huldtgren et al (1980)	35, C4 to C8, 3 months to 3 years	1. control (n = 23) 2. mouthpiece IMT and EMT plus air insufflation using a pump, 15 minutes once a day, 7 days a week, 6 weeks (n = 12)
Loveridge et al (1989)	12, C6/7, more than one year	1. control (n = 6) 2. mouthpiece IMT at 85% maximal SIP, 15 minutes twice a day, 5 days a week, 8 weeks (n = 6)
Gounden (1990)	40, C5 to C8, 4 months to 16 years	1. control (n = 20) 2. mouthpiece EMT at approximately 60% MEP, 5-8 minutes at least 5 times a day, 6 days a week, 8 weeks (n = 20)
Derrickson et al (1992)	11, C4/5 to C7, less than three months	1. mouthpiece IMT with resistance increased once able to do 3 successive 15 minute sessions; 15 minutes twice a day, 5 days a week, 7 weeks (n = 6) 2. abdominal weights IMT with maximum weight that didn't alter IC (mean weight of 11kg); 15 minutes twice a day, 5 days a week, 7 weeks (n = 5)
Biering-Sorensen et al (1991)	10, C4 to C8, 5 to 15 years	1. mask IMT and EMT with inspiratory resistance increased as tolerated and a fixed expiratory resistance, 15 minutes three times a day, 7 days a week, 6 weeks
Gross et al (1980)	6, C3 to T1, more than 1 year	1. mouthpiece IMT with least resistance that resulted in EMG evidence of diaphragmatic fatigue, resistance re-assessed at 8 weeks, 15 minutes twice a day, 6 days a week, 16 weeks
Hornstein and Ledsome (1986)	20, C4/5 to C7, less than 4 weeks	1. mouthpiece IMT with resistance increased as tolerated, 15 minutes twice a day initially, then once maximum resistance tolerated placed on an indefinite maintenance program of 15 minutes once a day, 2-3 times a week
Rutchik et al (1998)	10, C4 to C7, 2 to 17 years	1. mouthpiece IMT with resistance increased as tolerated, 15 minutes twice a day, 7 days a week, 8 weeks
Morrison (1988)	1, C1 mechanically ventilated, 8 months	1. biofeedback EMG to sternocleidomastoid and upper trapezius muscles, once a day, 6 sessions
Gallego et al (1993)	11, C5 to C7, 4 to 11 months	1. biofeedback EMG to scalene and sternocleidomastoid muscles, 9 sessions over a mean of 27 days
Clough (1983)	1, C5, 4 years	1. glossopharyngeal breathing, 14 sessions over 6 weeks
Walker et al (1989)	15, C4/5 to C7/8, more than 2 years	1. incentive spirometry 15 minutes, 3 - 5 times a week, plus arm cycle ergometry up to 30 minutes 3 times a week, 7 to 12 weeks. Workload on ergometer increased as tolerated

n = number; IMT = inspiratory muscle training; EMT = expiratory muscle training; MIP = maximal inspiratory pressure; MEP = maximal expiratory pressure; TLC = total lung capacity; VC = vital capacity; RV = residual volume; RMT = respiratory muscle training; SIP = sustainable inspiratory pressure (defined as the maximum inspiratory resistance through which the patient could breathe for 10 minutes);

Outcome variables	Results
MIP, MEP, TLC, VC, RV pre- and post-program and when possible 1 and 5 years post-program	MIP and MEP: significantly increased for RMT group post-program. Values returned almost to pre-program values at 5 years post-program for 5 patients. No MIP or MEP measures for control group. TLC, VC increased and RV decreased post-program for RMT group, no change for control group. Inconsistent follow up at 1 and 5 years. No statistical analysis. No percentage or absolute values available.
MIP, SIP, ABGs, FRC, TLC, IC, FRC, TLC, IC, RV pre- and post-program	MIP: significantly increased by 28% for control group (-82 to -105cmH_2O) and 40% for IMT group (-72 to -101cmH_2O); NS difference between groups. SIP: significantly increased by 29% for control group (-56 to -72cmH_2O) and 54% for IMT group (-50 to -77cmH_2O); NS difference between groups. ABGs, FRC, TLC, IC, RV: NS change.
MEP, VC pre- and post-program	MEP: increased by 5% for control group (44 to 46cmH_2O) and significantly increased by 55% for EMT group (44 to 68cmH_2O). EMT group significantly greater improvement than control group. VC: decreased by 7% for control group (1.5 to 1.4L) and significantly increased by 33% for EMT group (1.5 to 2.0L). EMT group significantly greater improvement than control group.
MIP, MVV, FVC, IC, PEFR pre- and post-program	All variables except IC: significantly increased (eg MIP increased by 66% for mouthpiece group [-35 to -58cmH_2O] and 105% for abdominal weights group [-21 to -43cmH_2O]; MVV increased by 40% for mouthpiece group [43 to 60L/min] and 25% for abdominal weights group [24 to 30L/min]); NS difference between groups.
FVC, FRC, TLC, RV, FEV_1, PEFR, MEF pre- and post-program	PEFR: significantly increased by 11% (66 to 74% predicted value) FVC, FRC, TLC, RV, FEV_1, MEF: NS change.
MIP, resistor size required to produce EMG signs of diaphragmatic fatigue	MIP: significantly increased by 37% (-62 to -85cmH_2O).No EMG signs of diaphragmatic fatigue at resistor which had previously provoked this finding.
MIP pre- and 3.5 weeks and 4 months after start of program	MIP: increased by 13% at 3.5 weeks (-40 to -45mmHg) and by 48% at 4 months (-40 to -59mmHg, 10 patients only). No statistical analysis.
MIP, MEP, FVC, FEV_1, TLC, FRC, RV, IC, ERV, V_T pre- and post-program and more than 6 months post-program	MIP, FVC, TLC, FRC: significantly increased post-program (eg MIP increased by 24% [-66 to -74cmH_2O], FVC increased by 11% [2.8 to 3.1L]). FEV_1, RV, ERV, V_T, MEP: NS change post-program. 6 months post-program: NS change from pre-program.
VC off ventilator	VC: increased by 1000% (50 to 550ml). No statistical analysis.
Inspiratory EMG levels	Inspiratory EMG levels: significantly increased across the 9 sessions.
VC pre- and post-program	VC: increased by 70% (2.3 to 3.9L). No statistical analysis.
FVC pre- and post-program	FVC: significantly increased by 25% (2.60 to 3.26L).

ABGs = arterial blood gases; FRC = functional residual capacity; IC = inspiratory capacity; NS = no significant; MVV = maximal voluntary ventilation; FVC = forced VC; PEFR = peak expiratory flow rate; FEV_1 = forced expiratory volume in one second; MEF = maximal expiratory flow rate; EMG = electromyographic; ERV = expiratory reserve volume; V_T = tidal volume.

respiratory muscle strength/endurance after RMT, there is only limited or anecdotal evidence that these beneficial changes translate into improvement in quality of life domains.

Discussion

This review reveals a lack of definitive research concerning the effectiveness of RMT for tetraplegic patients. There were methodological concerns with many of the studies reviewed – for example, there were only two randomised controlled studies, many studies failed to ensure that examiners were blinded to patients' groups and no studies discussed examiner reliability or the normal variance and reliability of the measurements performed. Most studies did ensure standardisation of patient posture during measurement of respiratory muscle strength/endurance and spirometry, which is an important issue, as these parameters vary according to not only body position (ie erect or supine) (Estenne and De Troyer 1987), but also head posture (Amodie-Storey et al 1996). The number of patients included in many of the studies was low, hence their ability to detect statistically significant differences between treatment groups is likely to have been low.

Despite these shortcomings, most of the studies reviewed demonstrated significant improvements in respiratory muscle strength and/or endurance and/or pulmonary function after IMT. However, as only one study of IMT included patients randomly allocated to a control group and, in this study, control group patients showed similar improvements to those in the IMT group even though they were at least one year post-injury, it is not clear whether these improvements represented spontaneous recovery or a true training effect. Furthermore, it is not known whether any improvements in respiratory muscle strength and/or endurance after a period of IMT translate into improvements in function and/or quality of life. The optimal type of IMT is not certain. Of the devices which have been studied, ie flow-resistive mouthpiece IMT, pressure threshold mouthpiece IMT and abdominal weights, one study demonstrated that mouthpiece devices were as effective as abdominal weights, but no studies have compared flow resistive mouthpiece IMT with pressure threshold mouthpiece IMT. It is important that, if IMT is to be conducted using flow-resistive mouthpiece devices, some attempt be made to control the respiratory pattern during the IMT. If this is not done, patients may change their respiratory pattern to one of slow, deep inspiration, such that the work imposed on the respiratory muscles may not be sufficient to produce a training effect (Goldstein 1993). Pressure threshold devices, where a minimal mouth pressure must be generated, and feedback devices that regulate the breathing pattern, may overcome these problems. The optimal regimen of IMT, in terms of the intensity, frequency and duration of training, cannot be identified from published research. In particular, it is not clear at what stage (if any) IMT should be commenced after SCI. The studies that have evaluated IMT have varied in the timing of commencement of IMT from only a few weeks to years post-injury, yet most studies have demonstrated improvement in outcome variables irrespective of the time post-injury. It is also not clear whether a maintenance program of IMT is required after an initial training period (although the results of Rutchik et al [1998] where patients had returned to pre-program levels six months after a RMT program suggest a maintenance program is necessary) and patient adherence to IMT has not been evaluated. Finally, it is unknown whether IMT, even if it can successfully meet the strength training principles of appropriate overload, will improve ventilatory function during activities of daily living.

As far as other methods of RMT are concerned, the effectiveness of EMT is unclear, although the evidence from the one randomised controlled study was positive (Gounden 1990). There has been only limited research into techniques to improve the strength of the accessory muscles of respiration in the neck and/or upper thorax for tetraplegic patients who are ventilator dependent. Nevertheless, from the evidence available, these techniques appear to improve pulmonary function significantly and have important clinical significance in terms of enabling patients to spend at least some time ventilator free. The effectiveness of glossopharyngeal breathing for tetraplegic patients is essentially unstudied, therefore its usefulness with this population is unknown.

Another important area of research that has not been studied is the value of exercise training for increasing respiratory muscle strength and/or endurance, as well as cardiovascular fitness, for tetraplegic patients. While there is limited evidence that aerobic training using an arm cranking ergometer can improve ventilatory muscle endurance of paraplegic subjects (Silva et al 1998), there do not appear to be any data on this subject for tetraplegic patients. In normal subjects and patients with chronic airflow limitation, arm exercise makes the upper trunk and shoulder girdle muscles (including the intercostals and accessory muscles of respiration) less available for ventilation, as they must serve a non-ventilatory role of stabilising the arms and torso. This shifts the inspiratory load onto the diaphragm and increases the expiratory work of the abdominal muscles (Celli 1994). In some studies, upper limb training for patients with chronic airflow limitation has significantly increased respiratory muscle strength and/or endurance (Celli 1993, Epstein et al 1991, Keens et al 1977). An active arm exercise training program (eg cycle ergometry) for tetraplegics (with at least a C5 level of function) who can have an arm ergometer adapted for independent use may result in the arms being able to perform more work and the ventilatory response being reduced at a certain workload. It may also improve respiratory muscle strength/endurance. Alternatively, the use of electrically stimulated leg exercise, either on its own or in addition to active arm exercise (or electrically stimulated arm exercise for tetraplegic patients with high lesions), could theoretically improve respiratory muscle strength/endurance as a result of the increased minute ventilation which is necessary to meet the increased oxygen demands and enable the elimination of the extra carbon dioxide produced during exercise. Electrically stimulated leg exercise may be of particular benefit, as it increases metabolic stress while reducing cardiac stress compared with arm exercise alone for tetraplegic patients (Hooker et al 1992). In theory, exercise could potentially be the most functionally beneficial means of RMT for tetraplegic patients, as it may improve respiratory muscle strength/endurance and cardiovascular fitness and, if active arm exercise is possible, increase the ability to perform upper limb activity. However, these hypotheses remain to be tested. As upper limb activity would also have the potential to result in respiratory muscle fatigue, it would be important to monitor respiratory function to ensure this did not occur.

Clearly, there is a need for more research to be undertaken to investigate the value of RMT for tetraplegic patients. Future studies need to include control groups to ensure that spontaneous recovery is not responsible for any improvements documented. Outcome variables should include measures of respiratory muscle strength and/or endurance and, importantly, broader areas of function and quality of life. Various functional scales, measures of dyspnoea during various activities of daily life, and health related quality of life questionnaires should be adaptable for use in this setting. An important area of research will be the identification of the optimal time to commence RMT after injury. It could be argued that RMT should be commenced in the early stages post-injury for all tetraplegic patients, with the aim of improving and maximising function. Alternatively, RMT may only be indicated for those patients whose early pulmonary function (spirometric parameters or measures of respiratory strength/endurance) is below a pre-determined level. Lastly, a case could be argued to delay RMT until spontaneous recovery has occurred and only commence RMT for those patients who have symptoms and signs suggestive of respiratory muscle weakness and/or fatigue. Clearly, the optimal approach cannot be answered given the present state of knowledge.

Based on the results of this review, the following recommendations are made to Australian physiotherapists working with tetraplegic patients: Firstly, as there currently is no definitive evidence that RMT improves respiratory muscle strength/endurance, function or quality of life more quickly than that which will be achieved with spontaneous recovery, its routine use during the rehabilitation of tetraplegic patients cannot be advocated at present. Secondly, if physiotherapists choose to use RMT for selected patients, it is essential that they ensure the RMT is of an adequate intensity for a training effect to occur (ie the resistance to inspiration/expiration must be set at an appropriate level and the breathing pattern controlled to ensure the overload principle is met), and that outcome is measured appropriately. Thirdly, as there is evidence that programs aimed at strengthening the accessory muscles of respiration for ventilator dependent tetraplegics do have significant benefits, these techniques should be considered by physiotherapists for use with this sub-group of patients. Finally, in view of the limited number of tetraplegic patients in Australia, if physiotherapists wish to be involved in research in this area, this is most likely to be successful if the trials are multi-centred or of a single case study design.

In summary, while respiratory muscle strength and/or endurance has been shown to increase after a period of IMT for tetraplegic patients, the lack of controlled studies means that spontaneous recovery cannot be excluded as being responsible for the improvements observed. The most effective method of IMT (in terms of the timing post-injury, type of device, intensity, frequency and duration) is not clear. Essentially, no or very few studies have been performed on the effectiveness of EMT and glossopharyngeal breathing for tetraplegic patients. Similarly, the role of exercise as a means of improving respiratory muscle strength/endurance is not known. Limited data suggest that programs aimed at strengthening the accessory muscles of respiration for ventilator dependent tetraplegics have statistically and clinically significant benefits, thus these techniques should at least be considered for this subgroup of tetraplegics.

Acknowledgments The authors would like to thank Dr Sue Jenkins, Dr Garry Allison and Ms Naomi Haensel for their helpful comments regarding this paper.

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